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DECLARATION

I, Ako Satoh, of Yanagida & Associates, 7F Shin-Yokohama KS Bldg., 3-18-3 Shin-Yokohama, Kohoku-ku, Yokohama-shi, Japan, hereby certify that I understand both English and Japanese, that the translation is true and correct, and that all statements are being made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Ako Satoh

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Dated this 7th day of February, 2005

11-293P02

[Name of Document] SPECIFICATION

[Title of the Invention] OPTICAL WAVELENGTH CONVERTING DEVICE AND PROCESS FOR PRODUCING THE SAME

[Scope of Demand for Patent]

[Claim 1] A process for producing an optical wavelength converting device having a periodic domain inversion structure, in which a periodic electrode is formed on one surface of a single-polarized ferroelectric substance having nonlinear optical effects, and an electric field is applied across the ferroelectric substance by the utilization of the periodic electrode in order to set regions of the ferroelectric substance, which stand facing the periodic electrode, as local area limited domain inversion regions, the process comprising the steps of:

forming a photosensitive resist layer on the one surface of the ferroelectric substance, the resist layer having properties such that, when light is irradiated to the resist layer, only exposed areas of the resist layer or only unexposed areas of the resist layer become soluble in a developing solvent;

exposing the resist layer to near field light in a periodic pattern with means for producing the near field light in the periodic pattern upon irradiation with exposure light;

developing the resist layer to form a periodic pattern in the resist layer; and

forming the periodic electrode on the one surface of the ferroelectric substance at positions corresponding to opening areas of the mask by utilizing the periodic pattern of the resist layer as a mask.

[Claim 2] A process for producing an optical wavelength converting device having a periodic domain inversion structure, in which a periodic electrode is formed on one surface of a single-polarized ferroelectric substance having nonlinear optical effects, and an electric field is applied across the ferroelectric substance by the utilization of the periodic electrode in order to set regions of the ferroelectric substance,

which stand facing the periodic electrode, as local area limited domain inversion regions, the process comprising the steps of:

forming an electrode material layer on the one surface of the ferroelectric substance;

forming a photosensitive resist layer on the electrode material layer, the resist layer having properties such that, when light is irradiated to the resist layer, only exposed areas of the resist layer or only unexposed areas of the resist layer become soluble in a developing solvent;

exposing the resist layer to near field light in a periodic pattern with means for producing the near field light in the periodic pattern upon irradiation with exposure light;

developing the resist layer to form a periodic pattern in the resist layer; and

etching the electrode material layer by utilizing the periodic pattern of the resist layer as a mask, so that the periodic electrode is formed at positions corresponding to opening areas of the mask.

[Claim 3] A process for producing an optical wavelength converting device having a periodic domain inversion structure, in which a periodic electrode is formed on one surface of a single-polarized ferroelectric substance having nonlinear optical effects, and an electric field is applied across the ferroelectric substance by the utilization of the periodic electrode in order to set regions of the ferroelectric substance, which stand facing the periodic electrode, as local area limited domain inversion regions, the process comprising the steps of:

forming a first resist layer and a second resist layer in this order on the one surface of the ferroelectric substance, the first resist layer being removable by etching, the second resist layer being photosensitive and having properties such that, when light is irradiated to the second resist layer, only exposed areas of the second resist layer or only unexposed areas of the second resist layer become soluble in a developing solvent;

exposing the second resist layer to near field light in a periodic pattern with means for producing the near field light in the periodic pattern upon irradiation with exposure light;

developing the second resist layer to form a periodic pattern in the resist layer;

etching the first resist layer by utilizing the periodic pattern of the second resist layer as an etching mask to form a periodic pattern composed of the first resist layer and the second resist layer; and

using the periodic pattern of the resist layer as an etching mask to form the periodic electrode on the one surface of the ferroelectric substance at positions corresponding to opening areas of the mask.

[Claim 4] A process for producing an optical wavelength converting device having a periodic domain inversion structure, in which a periodic electrode is formed on one surface of a single-polarized ferroelectric substance having nonlinear optical effects, and an electric field is applied across the ferroelectric substance by the utilization of the periodic electrode in order to set regions of the ferroelectric substance, which stand facing the periodic electrode, as local area limited domain inversion regions, the process comprising the steps of:

forming an electrode material layer on the one surface of the ferroelectric substance;

forming a first resist layer and a second resist layer in this order on the electrode material layer, the first resist layer being removable by etching, the second resist layer being photosensitive and having properties such that, when light is irradiated to the second resist layer, only exposed areas of the second resist layer or only unexposed areas of the second resist layer become soluble in a developing solvent;

exposing the second resist layer to near field light in a periodic pattern with means for producing the near field light in the periodic pattern upon irradiation with exposure light;

developing the second resist layer to form a periodic

pattern in the resist layer;

etching the first resist layer by utilizing the periodic pattern of the second resist layer as an etching mask to form a periodic pattern composed of the first resist layer and the second resist layer; and

etching the electrode material layer by utilizing the periodic pattern of the resist layer as an etching mask, so that the periodic electrode is formed at positions corresponding to opening areas of the mask.

[Claim 5] A process for producing an optical wavelength converting device as defined in Claim 3 or 4, characterized in that the second resist layer is formed to have a film thickness of at most 100 nm.

[Claim 6] A process for producing an optical wavelength converting device as defined in one of Claims 3 to 5, characterized in that the first resist layer is formed from a non-photosensitive material, and the etching performed for the first resist layer is dry etching.

[Claim 7] A process for producing an optical wavelength converting device as defined in one of Claims 1 to 6, characterized in that the exposure light has a wavelength falling within the range of 250 nm to 450 nm.

[Claim 8] A process for producing an optical wavelength converting device as defined in one of Claims 1 to 7, characterized in that:

the means for producing the near field light in the periodic pattern upon irradiation with exposure light is a mask for transferring the near field light through a metal pattern having opening areas which is formed on a member transmissive to the exposure light; and

the metal pattern is positioned in close contact with the resist layer, which is laid bare on the ferroelectric substance, or the metal pattern is positioned close to the resist layer, which is laid bare on the ferroelectric substance, such that the near field light reaches the resist layer, which is laid

bare on the ferroelectric substance, the exposure light being irradiated to the mask in this state.

[Claim 9] A process for producing an optical wavelength converting device as defined in one of Claims 1 to 7, characterized in that:

the means for producing the near field light in the periodic pattern upon irradiation with exposure light is an optical stamp constructed of a light-transmitting member, which is capable of transmitting the exposure light and has a concavity-convexity pattern formed on one surface, the optical stamp operating such that, when the exposure light is guided from within the light-transmitting member to the one surface of the light-transmitting member and is caused to undergo total reflection, the near field light in a pattern in accordance with the concavity-convexity pattern formed on the one surface of the light-transmitting member is radiated out; and

the optical stamp is positioned in close contact with the resist layer, which is laid bare on the ferroelectric substance, or the metal pattern is positioned close to the resist layer, which is laid bare on the ferroelectric substance, such that the near field light reaches the resist layer, which is laid bare on the ferroelectric substance, the exposure light being irradiated to the mask in this state.

[Claim 10] A process for producing an optical wavelength converting device as defined in one of Claims 1 to 7, characterized in that the means for producing the near field light is a probe provided with an opening having a diameter shorter than a wavelength of the exposure light, the probe being scanned for irradiation on the resist layer which is laid bare on the ferroelectric substance.

[Claim 11] A process for producing an optical wavelength converting device as defined in one of Claims 1 to 10, characterized in that the ferroelectric substance is $LiNbO_3$ doped with MgO.

[Claim 12] A process for producing an optical wavelength

converting device as defined in Claim 11, characterized in that the periodic electrode has an electrode line width of at most 0.3 μm.

[Claim 13] An optical wavelength converting device produced through the process as defined in one of Claims 1 to 12.

[Claim 14] An optical wavelength converting device, comprising a crystal of a Z-cut plate of $LiNbO_3$ doped with MgO, domain inversion regions being formed periodically in a bulk form in the crystal,

characterized in that the domain inversion regions are formed with a period falling within the range of 1.0μm to 4.6μm.

[Claim 15] An optical wavelength converting device, comprising a crystal of a Z-cut plate of $LiNbO_3$ doped with MgO, domain inversion regions being formed periodically in a bulk form in the crystal, characterized in that the optical wavelength converting device is constituted to radiate out a wavelength-converted wave having a wavelength falling within the range of 320 nm to 470 nm.

[Claim 16] An optical wavelength converting device comprising a crystal of a Z-cut plate of $LiNbO_3$ doped with MgO, domain inversion regions being formed periodically in a bulk form in the crystal as defined in Claim 14 or 15, characterized in that:

the domain inversion regions are formed with a period falling within the range of 1.0μm to 4.6μm; and

the optical wavelength converting device is constituted such that, when a fundamental wave having a wavelength falling within the range of 640 nm to 940 nm impinges upon the optical wavelength converting device, the optical wavelength converting device radiates out a second harmonic having a wavelength falling within the range of 320 nm to 470 nm with the period of the domain inversion regions acting as a first-order period for pseudo-phase matching.

[Claim 17] A solid laser comprising an optical wavelength converting device as defined in on of Claims 13 to 16,

characterized in that the solid laser being constituted to covert a produced laser beam into its second harmonic and to output the second harmonic.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

This invention relates to an optical wavelength converting device for converting a fundamental wave into its second harmonic or the like, in particular, such an optical wavelength converting device having a periodic domain inversion structure, and relates to a process for producing the same.

[0002]

This invention also relates to a solid laser for converting a produced laser beam into its second harmonic by the utilization of such an optical wavelength converting device and radiating out the second harmonic.

[0003]

[Description of the Related Art]

A technique, wherein a fundamental wave is converted into its second harmonic by the utilization of an optical wavelength converting device having a periodic domain inversion structure has been proposed by Bleombergen, et al. (see Phys. Rev., Vol. 127, No. 6, 1918 (1962)). The periodic domain inversion structure is provided with regions, in which spontaneous polarization (domain) of a ferroelectric substance having nonlinear optical effects is inverted periodically. With this technique, phase matching between a fundamental wave and its second harmonic can be effected by setting such that a period Λ of the domain inversion regions may be integral multiples of a coherence length Λc, which may be represented by the following formula:

$$\Lambda c=2\pi/\{\beta(2\omega)-2\beta(\omega)\} \quad \ldots (1)$$

where $\beta(2\omega)$ represents the propagation constant of the second harmonic, and $\beta(\omega)$ represents the propagation constant of the fundamental wave.

In cases where wavelength conversion is performed by using a bulk crystal of a nonlinear optical material, the wavelength at which the phase matching is effected is limited to a specific wavelength that is inherent to the crystal. However, with the proposed technique, the phase matching can be effected efficiently by selecting the period Λ of the domain inversion regions, which period satisfies Formula (1), with respect to an arbitrary wavelength.

[0004]

As one of techniques for forming the periodic domain inversion structure described above, as shown in Japanese Unexamined Patent Publication No. 7(1995)-72521, there has been known a technique in which after a periodic electrode in a predetermined pattern is formed on one surface of a single-polarized ferroelectric substance having nonlinear optical effects, an electric field is applied through corona charge across the ferroelectric substance by the utilization of the periodic electrode and a corona wire, which is located on the surface side of the ferroelectric substance opposite to the one surface of the ferroelectric substance, and regions of the ferroelectric substance which stand facing the periodic electrode are thereby set as local area limited domain inversion regions.

[0005]

In addition to the above-described technique based on corona-charging, there has been known, for example, as shown in Japanese Unexamined Patent Publication No. 4(1992)-335620, a technique for forming the periodic domain inversion structure, in which an entire-area electrode is formed on a surface of a ferroelectric substance on the side opposite to a surface on which a periodic electrode in a predetermined pattern is formed, an electric field is applied across the ferroelectric substance by the utilization of the entire-area electrode and the periodic electrode, and local area limited domain inversion regions are thereby formed.

[0006]

As a technique for forming the periodic electrode, as shown in Japanese Unexamined Patent Publication No. 10(1998)-170966, there has been known a technique wherein ridge regions having predetermined shapes in a predetermined pattern are formed on one surface of a ferroelectric substance, and electrode fingers of a periodic electrode are formed on the surfaces of the ridge regions.

[0007]

[Problems to be Solved by the Invention]

In cases where the periodic domain inversion structure is formed by the utilization of the periodic electrode in the manner described above, particularly as for a Z-cut ferroelectric substance plate, there is a strong possibility that, as the period of the periodic electrode is set to be short in order for a second harmonic, or the like, having a short wavelength to be generated, domain inversion regions, which are adjacent to each other and extend through the ferroelectric substance from the areas corresponding to electrode fingers of the periodic electrode, will become connected with each other.

[0008]

The problems described above will be described with reference to FIG. 7. This drawing shows results of evaluation of periodicity of various bulk-form periodic domain inversion structures, each of which is formed in $LiNbO_3$ doped with MgO (hereinbelow referred to simply as MgO-LN) by the utilization of a periodic electrode having an electrode line width (i.e., the line width of each of the electrode fingers of the periodic electrode) A, the evaluation being made with respect to various different values of a period Λ of domain inversion regions and various different values of a duty ratio D ($D=A/\Lambda$). In FIG. 7, the "o" mark indicates that the periodicity is good over a length of at least 1 mm. The "Δ" mark indicates that the periodicity is good only over a length of less than 1 mm or that the regions in which the periodicity is good occur sporadically.

The "×" mark indicates that few regions in which the periodicity is good occur.

[0009]

As shown herein, in order to provide better periodicity of the periodic domain inversion structure, it is efficient to decrease the duty ratio D, i.e. to decrease the electrode line width A. Also, in cases where the period Λ is at most 7 μm, it is necessary to decrease the duty ratio D to 0.15 or less. In cases where the domain inversion length is approximately 1 mm, the duty ratio D should thus be set at a value not more than 0.15. For larger areas (where the domain inversion length is approximately 3 mm to 4 mm), the inversion periodicity may be stabilized and enhanced by further decreasing the duty ratio D.

[0010]

In cases where the periodic domain inversion structure is formed by the utilization of the periodic electrode, each of the domain inversion regions is formed over a region slightly wider than the region corresponding to the electrode line width A due to the spread of the electric field. Therefore, even if the duty ratio D is set at a value smaller than 0.5, the periodic domain inversion structure can be formed, in which the ratio between the width of each domain inversion region and the width of each non-inversion region is approximately equal to 1:1.

[0011]

In view of the above circumstances, in cases where a second harmonic, or the like, having a short wavelength falling within, for example, the blue region or the ultraviolet region is to be generated, it is necessary for a periodic electrode having a markedly small electrode line width A to be formed. However, heretofore, it was difficult to form a periodic electrode having a markedly small electrode line width. Particularly, with respect to the optical wavelength converting device in which the periodic domain inversion structure is formed in the bulk form in a crystal of a Z-cut plate of MgO-LN,

an example in which a second harmonic having a wavelength falling within the wavelength region of at most 470 nm has not heretofore been reported. The representation "periodic domain inversion structure in a bulk form in a crystal of a Z-cut plate" as used herein means the periodic domain inversion structure in which the domain inversion regions are formed over a range extending from a position in the vicinity of a +Z surface of the plate to a position in the vicinity of a -Z surface of the plate.

[0012]

In cases where a second harmonic having a wavelength falling within the wavelength region of at most 470 nm is to be generated with the aforesaid type optical wavelength converting device, if the electrode line width A of the periodic electrode employed for the formation of the periodic domain inversion structure is set at a value of at most 0.3μm, a periodic domain inversion structure reliably having good periodicity over a wide area can be formed.

[0013]

As techniques for forming a periodic electrode having a small electrode line width A, an EB drawing technique, a FIB deposition technique, and the like, have heretofore been known. However, the conventional techniques for forming a periodic electrode having a small electrode line width A are not appropriate for large-area patterning and have a low throughput and a productivity markedly lower than the level of productivity required for mass production.

[0014]

As a technique capable of coping with large-area patterning, a technique utilizing a contraction exposure apparatus has heretofore been known. However, the technique utilizing the contraction exposure apparatus has the drawbacks in that the cost of the contraction exposure apparatus is markedly high and it is difficult to obtain an electrode line width A shorter than the wavelength of exposure light.

[0015]

The present invention has been made in view of the aforementioned circumstances, and an object of the present invention is to provide a process for producing an optical wavelength converting device, enabling to form a periodic electrode having a markedly small electrode line width, and in turn making it possible to form a bulk-form periodic domain inversion structure having domain inversion regions with a markedly short period as never before.

[0016]

Another object of the present invention is to provide an optical wavelength converting device having a bulk-form periodic domain inversion structure having a markedly short period as never before.

[0017]

A further object of the present invention is to provide a solid laser which can convert a produced layer into its second harmonic having a markedly short wavelength by the utilization of the above-mentioned optical wavelength converting device, and can output the second harmonic.

[0018]

[Means for Solving the Problems]

According to the present invention, there is provided, as described above, a process for producing an optical wavelength converting device having a periodic domain inversion structure, in which a periodic electrode is formed on one surface of a single-polarized ferroelectric substance having nonlinear optical effects, and an electric field is applied across the ferroelectric substance by the utilization of the periodic electrode in order to set regions of the ferroelectric substance, which stand facing the periodic electrode, as local area limited domain inversion regions, the process comprising the steps of:

forming a photosensitive resist layer on the one surface of the ferroelectric substance, the resist layer having

properties such that, when light is irradiated to the resist layer, only exposed areas of the resist layer or only unexposed areas of the resist layer become soluble in a developing solvent;

exposing the resist layer to near field light in a periodic pattern with means for producing the near field light in the periodic pattern upon irradiation with exposure light;

developing the resist layer to form a periodic pattern in the resist layer; and

forming the periodic electrode on the one surface of the ferroelectric substance at positions corresponding to opening areas of the mask by utilizing the periodic pattern of the resist layer as a mask.

[0019]

Further, according to the present invention, there is provided another process for producing an optical wavelength converting device having a periodic domain inversion structure, in which a periodic electrode is formed on one surface of a single-polarized ferroelectric substance having nonlinear optical effects, and an electric field is applied across the ferroelectric substance by the utilization of the periodic electrode in order to set regions of the ferroelectric substance, which stand facing the periodic electrode, as local area limited domain inversion regions, the process comprising the steps of:

forming an electrode material layer on the one surface of the ferroelectric substance;

forming a photosensitive resist layer on the electrode material layer, the resist layer having properties such that, when light is irradiated to the resist layer, only exposed areas of the resist layer or only unexposed areas of the resist layer become soluble in a developing solvent;

exposing the resist layer to near field light in a periodic pattern with means for producing the near field light in the periodic pattern upon irradiation with exposure light;

developing the resist layer to form a periodic pattern

in the resist layer; and

etching the electrode material layer by utilizing the periodic pattern of the resist layer as a mask, so that the periodic electrode is formed at positions corresponding to opening areas of the mask.

[0020]

Still further, according to the present invention, there is provided another process for producing an optical wavelength converting device having a periodic domain inversion structure, in which a periodic electrode is formed on one surface of a single-polarized ferroelectric substance having nonlinear optical effects, and an electric field is applied across the ferroelectric substance by the utilization of the periodic electrode in order to set regions of the ferroelectric substance, which stand facing the periodic electrode, as local area limited domain inversion regions, the process comprising the steps of:

forming a first resist layer and a second resist layer in this order on the one surface of the ferroelectric substance, the first resist layer being removable by etching, the second resist layer being photosensitive and having properties such that, when light is irradiated to the second resist layer, only exposed areas of the second resist layer or only unexposed areas of the second resist layer become soluble in a developing solvent;

exposing the second resist layer to near field light in a periodic pattern with means for producing the near field light in the periodic pattern upon irradiation with exposure light;

developing the second resist layer to form a periodic pattern in the resist layer;

etching the first resist layer by utilizing the periodic pattern of the second resist layer as an etching mask to form a periodic pattern composed of the first resist layer and the second resist layer; and

using the periodic pattern of the resist layer as an etching mask to form the periodic electrode on the one surface

of the ferroelectric substance at positions corresponding to opening areas of the mask.

[0021]

Still further, according to the present invention, there is provided another process for producing an optical wavelength converting device having a periodic domain inversion structure, in which a periodic electrode is formed on one surface of a single-polarized ferroelectric substance having nonlinear optical effects, and an electric field is applied across the ferroelectric substance by the utilization of the periodic electrode in order to set regions of the ferroelectric substance, which stand facing the periodic electrode, as local area limited domain inversion regions, the process comprising the steps of:

forming an electrode material layer on the one surface of the ferroelectric substance;

forming a first resist layer and a second resist layer in this order on the electrode material layer, the first resist layer being removable by etching, the second resist layer being photosensitive and having properties such that, when light is irradiated to the second resist layer, only exposed areas of the second resist layer or only unexposed areas of the second resist layer become soluble in a developing solvent;

exposing the second resist layer to near field light in a periodic pattern with means for producing the near field light in the periodic pattern upon irradiation with exposure light;

developing the second resist layer to form a periodic pattern in the resist layer;

etching the first resist layer by utilizing the periodic pattern of the second resist layer as an etching mask to form a periodic pattern composed of the first resist layer and the second resist layer; and

etching the electrode material layer by utilizing the periodic pattern of the resist layer as an etching mask, so that the periodic electrode is formed at positions corresponding to opening areas of the mask.

[0022]

It is preferable that the second resist layer is formed to have a film thickness of at most 100 nm. Meanwhile, it is preferable that the first resist layer is formed from a non-photosensitive material, and the etching performed for the first resist layer is dry etching.

[0023]

In the processes for producing an optical wavelength converting device in accordance with the present invention, the exposure light should preferably have a wavelength falling within the range of 250 nm to 450 nm.

[0024]

On the other hand, as the means for producing the near field light, a mask for transferring the near field light through a metal pattern having opening areas which is formed on a member transmissive to the exposure light may be preferably adopted. In this case, it is preferable that the metal pattern is positioned in close contact with the resist layer, which is laid bare on the ferroelectric substance, or the metal pattern is positioned close to the resist layer, which is laid bare on the ferroelectric substance, such that the near field light reaches the resist layer, which is laid bare on the ferroelectric substance, the exposure light being irradiated to the mask in this state.

[0025]

As the means for producing the near field light, an optical stamp constructed of a light-transmitting member, which is capable of transmitting the exposure light and has a concavity-convexity pattern formed on one surface, the optical stamp operating such that, when the exposure light is guided from within the light-transmitting member to the one surface of the light-transmitting member and is caused to undergo total reflection, the near field light in a pattern in accordance with the concavity-convexity pattern formed on the one surface of the light-transmitting member is radiated out. In this case,

it is also preferable that the optical stamp is positioned in close contact with the resist layer, which is laid bare on the ferroelectric substance, or the optical stamp is positioned close to the resist layer, which is laid bare on the ferroelectric substance, such that the near field light reaches the resist layer, which is laid bare on the ferroelectric substance, the exposure light being irradiated to the mask in this state.

[0026]

It is also possible to use, as the means for producing the near field light, a probe provided with an opening having a diameter shorter than a wavelength of the exposure light, and scanning the probe to irradiate the resist layer which is laid bare on the ferroelectric substance.

[0027]

Also, in the processes for producing an optical wavelength converting device in accordance with the present invention, the ferroelectric substance should preferably be $LiNbO_3$ doped with MgO (MgO-LN). In such cases, the periodic electrode should preferably have an electrode line width of at most 0.3 μm.

[0028]

The present invention also provides an optical wavelength converting device, comprising a crystal of a Z-cut plate of MgO-LN described above, domain inversion regions being formed periodically in a bulk form in the crystal, characterized in that the domain inversion regions are formed with a period falling within the range of 1.0 μm to 4.6 μm.

[0029]

The present invention further provides an optical wavelength converting device, comprising a crystal of a Z-cut plate of MgO-LN, domain inversion regions being formed periodically in a bulk form in the crystal, characterized in that the optical wavelength converting device is constituted to radiate out a wavelength-converted wave having a wavelength

falling within the range of 320 nm to 470 nm.

[0030]

The present invention still further provides another optical wavelength converting device, comprising a crystal of a Z-cut plate of MgO-LN, domain inversion regions being formed periodically in a bulk form in the crystal, characterized in that:

wherein the domain inversion regions are formed with a period falling within the range of 1.0 μm to 4.6 μm; and

the optical wavelength converting device is constituted such that, when a fundamental wave having a wavelength falling within the range of 640 nm to 940 nm impinges upon the optical wavelength converting device, the optical wavelength converting device radiates out a second harmonic having a wavelength falling within the range of 320 nm to 470 nm with the period of the domain inversion regions acting as a first-order period for pseudo-phase matching.

[0031]

Meanwhile, the present invention also provides a solid laser, comprising any of the optical wavelength converting devices in accordance with the present invention, the solid laser being constituted to covert a produced laser beam into its second harmonic and to radiate out the second harmonic.

[0032]

[Advantageous effect of the Invention]

With the processes for producing an optical wavelength converting device in accordance with the present invention, the photosensitive resist is exposed to the near field light, which oozes from the periodic pattern having a line width shorter than the wavelength of the exposure light, and the exposed resist is then developed. As a result, a periodic electrode having an electrode line width not more than 100 nm (i.e. a period not more than 200 nm) which has been considered as the highest possible can be formed. Thus a periodic electrode having a short electrode line width, which was impossible with conventional

lithography, can be obtained.

[0033]

Specifically, when the periodic electrode is formed on the one surface of the ferroelectric substance by utilizing the periodic pattern of the resist layer as a mask, the periodic electrode being formed at the positions corresponding to the opening areas of the mask, it is sufficient to form each opening area of the mask to have a line width of not more than 100 nm.

[0034]

On the other hand, when the electrode material layer is formed on the one surface of the ferroelectric substance, the electrode material layer is etched by utilizing the periodic pattern of the resist layer as the etching mask, such that the portions of the electrode material layer at the positions corresponding to the opening areas of the mask are removed by the etching, and the periodic electrode is thereby formed, the line width of each of the areas other than the opening areas of the mask (i.e., the line width of each of the areas remaining as the resist layer) needs to be set at a value of at most 100 nm.

[0035]

For the process wherein the double-layered resist comprising the first resist layer and the second resist layer is employed, also when the ferroelectric substance has a step-like area and an area, to which the near field light cannot reach if only one resist layer is formed, occurs, the first resist layer can act to form a flat surface, and therefore the film thickness of the second resist, which is photosensitive and is formed on the first resist layer, can be uniformized. Accordingly, the near field light can be radiated out uniformly even in a large-area pattern, and a fine pattern of the second resist layer, which is photosensitive, can be formed. The first resist layer is then patterned with a conventional etching technique by utilizing the pattern of the photosensitive second resist layer as the mask. In this manner, a fine pattern can

be formed easily and at a low cost.

[0036]

Additionally, with the processes for producing an optical wavelength converting device in accordance with the present invention, wherein the mask provided with the aforesaid metal pattern or the optical stamp provided with the concavity-convexity pattern is employed as the means for producing the near field light, in contrast to the case of scanning exposure, the exposure of a large-area periodic pattern can be performed instantaneously, and therefore the optical wavelength converting device can be produced with a high throughput and at a low cost.

[0037]

With the processes for producing an optical wavelength converting device in accordance with the present invention, wherein the periodic electrode having a markedly small line width is capable of being formed in the manner described above, the optical wavelength converting device comprising a crystal of a Z-cut plate of MgO-LN, in which the domain inversion regions are formed periodically in a bulk form in the crystal, can be obtained, wherein the domain inversion regions are formed with a period falling within the range of 1.0 μm to 4.6 μm, and wherein the optical wavelength converting device is constituted such that, when a fundamental wave having a wavelength falling within the range of 640 nm to 940 nm impinges upon the optical wavelength converting device, the optical wavelength converting device radiates out a second harmonic having a wavelength falling within the range of 320 nm to 470 nm with the period of the domain inversion regions acting as the first-order period for the pseudo-phase matching.

[0038]

As the optical wavelength converting device comprising a crystal of a Z-cut plate of MgO-LN, in which the domain inversion regions are formed periodically in a bulk form in the crystal, an optical wavelength converting device capable of

radiating out a second harmonic having a wavelength of at most 470 nm has not heretofore been furnished. Since the absorption end of MgO-LN is 320 nm, it is practically impossible to radiate a second harmonic having a wavelength shorter than 320 nm from the optical wavelength converting device.

[0039]

[Embodiments of the Invention]

The present invention will hereinbelow be described in further detail with reference to the accompanying drawings. FIG. 1 and FIG. 2 show steps of producing an optical wavelength converting device in a first embodiment of the process for producing an optical wavelength converting device in accordance with the present invention. FIG. 1 shows steps of forming a periodic electrode. FIG. 2 shows a manner where a spontaneous polarization (domain) of a ferroelectric substance is inverted through the use of the periodic electrode having been formed with the steps shown in FIG. 1.

[0040]

First, how the periodic electrode is formed will be described hereinbelow with reference to FIG. 1. In this embodiment, MgO-LN is employed as the ferroelectric substance having nonlinear optical effects. Firstly, as illustrated in FIG. 1(1), a Z-cut MgO-LN plate 10 is provided. The MgO-LN plate 10 is subjected to single polarization, and the two Z surfaces of the MgO-LN plate 10 are subjected to mirror polishing such that the MgO-LN plate 10 has the thickness of 0.3 mm.

[0041]

Thereafter, as illustrated in FIG. 1(2), a resist layer 11 made up of a photosensitive material is formed with a spin-coating technique or a spraying technique on one surface (+Z surface) 10a of the MgO-LN plate 10. The thickness of the resist layer 11 should be a value approximately equal to or smaller than the oozing depth, which is ordinarily considered as approximately 50 nm, of near field light.

[0042]

Then, as illustrated in FIG. 1(3), a mask 12 for generating the near field light in a periodic pattern is brought into close contact with the resist layer 11. The mask 12 comprises a mask substrate, which is made of a dielectric material such as glass, and a lattice-like metal pattern, which has fine opening areas 12a and is formed on the mask substrate. In this embodiment, as will be clear from the later explanation, each opening area 12a of the metal pattern corresponds to one of electrode fingers of the periodic electrode to be formed, and each metal area 12b corresponds to one of spaces between each adjacent electrode fingers.

[0043]

The mask 12 is located such that the opening areas 12a of the metal pattern are arranged in X-axis direction of the MgO-LN plate 10. Also, a period Λ of the metal pattern of the mask 12 is set at 2.1 μm so as to act as the first-order period with respect to a wavelength of 380 nm of a second harmonic, which will be described later.

[0044]

As illustrated in FIG. 1(4), when the rear side of the mask 12 (i.e., from the upper side in FIG. 1(4)) to the mask 12 is then irradiated with exposure light L such as i-ray (having a wavelength of 365 nm), near field light Ln oozes from the opening areas 12a of the metal pattern, whereby the resist layer 11 is exposed to the near field light Ln.

[0045]

Thereafter, the resist layer 11 is developed with a developing solution, and the exposed portions of the resist layer 11 become soluble in a developing solvent. In this manner, as illustrated in FIG. 1(5), a positive type periodic pattern 11a of the resist layer 11 is formed. Thereafter, as illustrated in FIG. 1(6), the periodic pattern 11a is utilized as a mask, and chromium (Cr) 13 acting as an electrode material is deposited to a thickness of, for example, 20 nm by vacuum evaporation. As a result, Cr 13 is deposited on a one surface

10a of the MgO-LN plate 10 and only at positions corresponding to opening areas of the periodic pattern 11a of the resist layer 11. In lieu of Cr 13 being deposited by vacuum evaporation, tantalum (Ta) may be deposited by a sputtering technique or the like.

[0046]

Thereafter, as illustrated in FIG. 1(7), the positive type periodic pattern 11a of the resist layer 11 is removed by a lift-off technique, and a periodic electrode 13a having a period Λ of 2.1μm is thereby formed on the one surface 10a of the MgO-LN plate 10. Since the mask 12 was disposed in the orientation as described above, the electrode fingers constituting the periodic electrode are arranged side by side in a row in the X-axis direction of the MgO-LN plate 10.

[0047]

The width of each of the opening areas 12a of the metal pattern is set at 0.2 μm, and therefore an electrode line width A of the periodic electrode 13a is set at 0.2 μm. Accordingly, in this case, a duty ratio D ($D=A/\Lambda$) of the periodic electrode 13a is equal to 0.1, and the value of the duty ratio D is lower than the value of 0.15 as described above.

[0048]

How the spontaneous polarization (domain) of the MgO-LN plate 10 is inverted by the utilization of the periodic electrode 13a will be described hereinbelow with reference to FIG. 2. The MgO-LN plate 10 is disposed on an electrically conductive jig 1 such that the periodic electrode 13a is in contact with the electrically conductive jig 1. This electrically conductive jig 1 is formed from an electrically conductive material such as copper or stainless steel, and is grounded through a grounding wire 2.

[0049]

In this state, an electric field is applied through corona charge across the MgO-LN plate 10 by the utilization of the corona wire 3, which is disposed above a -Z surface 10b of the

MgO-LN plate 10, and the high voltage electric source 4, which is connected to the corona wire 3. At this time, the temperature of the MgO-LN plate 10 is set at 100 °C, the distance between the corona wire 3 and the MgO-LN plate 10 is set at 10 mm, and an electric voltage of 5 kV is applied for one second from the high voltage electric source 4 via the corona wire 3. After the electric field has been applied, the periodic electrode 13a is removed.

[0050]

Then, the Y surface of the MgO-LN plate 10 was cut and polished. Thereafter, selective etching was performed by use of a mixed etching solution containing hydrofluoric acid and nitric acid. When the cross-section (the Y surface) of the MgO-LN plate 10 was observed, it was confirmed that, at positions corresponding to the positions of the electrode fingers of periodic electrode 13a, periodic domain inversion regions were formed with the predetermined period corresponding to the period of the periodic electrode 13a such that each periodic domain inversion regions was formed uniformly to extend from the -Z surface to the +Z surface and had a uniform shape in the Y surface.

[0051]

An optical wavelength converting device constructed of the MgO-LN plate 10 will be described hereinbelow with reference to FIG. 3. In the manner described above, periodic domain inversion regions 21 are formed, which is arranged side by side in a row in the X axis direction of the MgO-LN plate 10. Thereafter, the +X surface and the -X surface of the MgO-LN plate 10 are polished. Non-reflection coating layers are then formed on the +X surface and the -X surface of the MgO-LN plate 10, and light passage surfaces 20a and 20b are thereby formed. In this manner, a bulk crystal type optical wavelength converting device 20 shown in FIG. 3 is obtained.

[0052]

The bulk crystal type optical wavelength converting

device 20 having the periodic domain inversion structure is located on an output side of an Ar laser pumped titanium sapphire laser 22 shown in FIG 3. A laser beam 23 from the Ar laser pumped titanium sapphire laser 22 was converged by a converging lens 24, and caused to enter the optical wavelength converting device 20. In this case, in order to produce phase matching with respect to the fundamental wave having a wavelength of 760 nm and the second harmonic having a wavelength of 380 nm, dispersion due to variation of the refractive index of the MgO-LN for different wavelengths is taken into consideration, and the period Λ of the periodic domain inversion regions 21. (which period is equal to the period of the periodic electrode 13a) is set at 2.1 μm.

[0053]

The Ar laser pumped titanium sapphire laser 22 emits the laser beam 23 having a wavelength of 760 nm as the fundamental wave. The output power of the Ar laser pumped titanium sapphire laser 22 is 400 mW. The laser beam 23 impinges upon the bulk crystal type optical wavelength converting device 20 and is converted into a second harmonic 25 having a wavelength of 380 nm, which is one-half of the wavelength of the laser beam 23. The second harmonic 25 undergoes phase matching (i.e., the pseudo-phase matching) in the periodic domain inversion regions. As described above, the periodic domain inversion regions 21 have good periodicity, and therefore, good phase matching is produced and the second harmonic 25 with power of 0.5 mW is obtained.

[0054]

The process for producing an optical wavelength converting device in accordance with a second embodiment of the invention will be described hereinbelow with reference to FIG. 4. In FIG. 4, the same reference numerals are used to denote the same elements as those in FIG. 1 and a description thereof will not be given unless otherwise required, and so on.

[0055]

Firstly, as illustrated in FIG. 4(1), the MgO-LN plate

10 of the same type as that employed in the first embodiment is provided. A Cr layer 30 having a thickness of 20 nm as an electrode material layer, a first resist layer 31 made of an organic high-molecular weight material, and a second resist layer 32 made of a photosensitive material are formed in this order on the one surface (+Z surface) 10a of the MgO-LN plate 10 and with a spin coating technique or a spraying technique. The first resist layer 31 and the second resist layer 32 thus constitute a double-layered resist 33.

[0056]

Thereafter, as illustrated in FIG. 4(2), the mask 12, which is of the same type as that employed in the first embodiment, is brought into close contact with the double-layered resist 33. Also in this case, the mask 12 having the metal areas 12b and opening areas 12a of the metal pattern are disposed such that the opening areas are arranged side by side in a row in the X axis direction of the MgO-LN plate 10. Also in this embodiment, as will be clear from the explanation made later, each opening area of the metal pattern corresponds to one of electrode fingers of the periodic electrode to be formed, and each metal area 12b corresponds to one of spaces between each adjacent electrode fingers.

[0057]

As illustrated in FIG. 1(3), when the rear side of the mask 12 (i.e., from the upper side in FIG. 1(3)) to the mask 12 is then irradiated with exposure light L such as i-ray (having a wavelength of 365 nm), near field light Ln oozes from the opening areas 12a of the metal pattern, whereby the second resist layer 32 is exposed to the near field light Ln.

[0058]

Thereafter, the second resist layer 32 is developed with a developing solution, and the exposed portions of the resist layer 11 become soluble in a developing solvent. In this manner, as illustrated in FIG. 4(4), a negative type periodic pattern is formed. Thereafter, as illustrated in FIG. 4(5), the periodic

pattern of the second resist layer 32 is utilized as a mask, and the first resist layer 31 and the Cr layer 30 are subjected to dry etching with an O_2 plasma.

[0059]

Thereafter, as illustrated in FIG. 4(6), the second resist layer 32 and the first resist layer 31 are removed, and a periodic electrode 30a made of Cr is thereby formed on the one surface 10a of the MgO-LN plate 10. Since the mask 12 was disposed in the orientation as described above, the electrode fingers constituting the periodic electrode are arranged side by side in a row in the X-axis direction of the MgO-LN plate 10.

[0060]

The quality of the first resist layer 31 does not deteriorate due to exposure to light. Therefore, when the first resist layer 31 is dissolved, both of the layers 31 and 32 can be removed easily. Alternatively, these layers may be peeled off with plasma ashing.

[0061]

The photosensitive resist constituting the second resist layer 32 may be a positive type resist having properties such that when the resist is exposed to light, only the exposed portions of the resist becomes soluble in a developing solution. Further, the thickness of the second resist layer 32 should preferably be approximately identical with the oozing depth of the near field light or shorter than the oozing depth of the near field light.

[0062]

Basically, any materials capable of being etched with the O_2 plasma may be employed as the organic high-molecular weight material constituting the first resist layer 31.

[0063]

When the periodic electrode 30a is embodied as described above on the one surface 10a of the MgO-LN plate 10, the spontaneous polarization (domain) of the MgO-LN plate 10 is

inverted by the utilization of the periodic electrode 30a. The domain inversion processing may be performed by using, for example, the apparatus shown in FIG. 3.

[0064]

The first resist layer and the second resist layer will hereinbelow be described in more detail.

[0065]

The first resist layer is formed from a material capable of undergoing dry etching, particularly an organic high-molecular weight material. It is desirable that the first resist layer does not form an intermediated mixed layer with the second resist layer overlaid on the first resist layer. Therefore, the first resist layer should preferably be formed from an organic high-molecular weight material, which does not dissolve in the solvent employed in the second resist layer. Alternatively, the first resist layer should preferably be formed from an organic high-molecular weight material, which dissolves at normal temperatures in the solvent employed in the second resist layer, and which is capable of being converted with processing, such as heating, into a crosslinked network structure that substantially forms no intermediated mixed layer with the second resist layer.

[0066]

Examples of the latter include a technique wherein a layer of a resist for i-rays or a resist for g-rays, which contains a novolak resin and a naphthoquinone diazide compound and is utilized for production of semiconductor devices, or the like, is applied to a necessary film thickness and is thereafter cured with heat treatment. Alternatively, a technique may be employed, wherein a layer of a negative type resist, which contains an alkali-soluble resin, such as a novolak resin or a polyhydroxystyrene, an acid crosslinking agent, and a photo acid generating agent, is applied and is thereafter cured with entire-surface exposure to light. Alternatively, a technique may be employed, wherein a layer of a negative type resist, which

contains an alkali-soluble resin, such as a novolak resin or a polyhydroxystyrene, a polyfunctional monomer, and a photo-polymerization initiating agent or a thermal polymerization initiating agent, is applied and is thereafter cured with entire-surface exposure to light or with heat treatment.

[0067]

The first resist layer 31 may also contain various additives (e.g., furalene and its derivatives) for various purposes.

[0068]

The second resist layer is formed from a photosensitive resist material having properties such that, when the resist material is exposed to the near field light, only the exposed portions of the resist material or only the unexposed portions of the resist material become soluble in a developing solvent, and the other portions of the resist material have dry etching resistance. The resist material should preferably be a material, which contains a compound having silicon atoms and in which the proportion of silicon in the solid content is equal to at least a predetermined value. In cases where the dry etching is performed with an oxygen-containing plasma, from the view point of oxygen plasma resistance, the proportion of silicon in the solid content in the resist material should preferably be comparatively high. However, ordinarily, if the proportion of silicon is excessively high, the pattern forming characteristics, edge roughness of the pattern or residues, and the like, will become bad. Therefore, the proportion of silicon in the solid content in the resist material should preferably be at least 1%, should more preferably fall within the range of 4% to 50%, and should most preferably fall within the range of 5% to 30%.

[0069]

Examples of the resist materials, which may be employed for the second resist layer 32, include the resist materials

described in Japanese Patent Nos. 2035509, 2094657, 2597163, 2606652, 2646241, 2646288, and 2646289; Japanese Unexamined Patent Publication Nos. 60(1985)-191245, 62(1987)-247350, 62(1987)-36661, 62(1987)-36662, 62(1987)-38452, 62(1987)-96526, 62(1987)-136638, 62(1987)-153853, 62(1987)-159141, 62(1987)-220949, 62(1987)-229136, 62(1987)-240954, 63(1988)-91654, 63(1988)-195649, 63(1988)-195650, 63(1988)-218948, 63(1988)-220241, 63(1988)-220242, 63(1988)-241542, 63(1988)-239440, 63(1988)-313149, 1(1989)-44933, 1(1989)-46746, 1(1989)-46747, 1(1989)-76046, 1(1989)-106042, 1(1989)-102550, 1(1989)-142720, 1(1989)-201653, 1(1989)-222254, 1(1989)-283555, 2(1990)-29652, 2(1990)-3054, 2(1990)-99954, 3(1991)-100553, 4(1992)-36754, 4(1992)-36755, 4(1992)-104252, 4(1992)-106549, 4(1992)-107460, 4(1992)-107562, 4(1992)-130324, 4(1992)-245248, 6(1994)-27670, 6(1994)-118651, 6(1994)-184311, 6(1994)-27671, 6(1994)-35199, 6(1994)-43655, 6(1994)-95385, 6(1994)-202338, 6(1994)-342209, 7(1995)-114188, 8(1996)-29987, 8(1996)-160620, 8(1996)-160621, 8(1996)-160623, 8(1996)-193167, and 10(1998)-319594; Japanese Patent Publication Nos. 6(1994)-7259, 6(1994)-42075, 6(1994)-56492, 6(1994)-79160, 6(1994)-84432, 7(1995)-27211, 7(1995)-60266, 7(1995)-69610, 7(1995)-99435, 7(1995)-111582, and 7(1995)-113772; U.S. Patent Nos. 4689289 and 4822716; EP No. 229629A1; and Japanese Patent Application Nos. 10(1998)-354878, 11(1999)-31591 and 11(1999)-20224.

[0070]

Among them, materials capable of being developed with an aqueous alkali developing solution are preferable for the capability of forming a good pattern with high developing power such that no organic waste liquid is produced and little swelling occurs. More specifically, pattern forming materials, which contain a water-insoluble, aqueous alkali-soluble, silicon-containing polymer and a photosensitive compound, are

preferable.

[0071]

More specifically, the following pattern forming materials are preferable: pattern forming materials, which contain a water-insoluble, aqueous alkali-soluble, silicone-containing polymer and a naphthoquinone diazide compound and/or a diazo ketone compound; positive types of pattern forming materials, which contain a water-insoluble, aqueous alkali-soluble, silicone-containing polymer, a compound capable of generating an acid with exposure to active light rays or radiation, and a high- or low-molecular weight compound having a group decomposable with an acid and having properties such that the solubility in an aqueous alkali developing solution increases by the action of an acid; negative types of pattern forming materials, which contain a functional group-containing, water-insoluble, silicone-containing polymer having a group decomposable with an acid and having properties such that the solubility in an aqueous alkali developing solution increases by the action of an acid, a compound capable of generating an acid with exposure to active light rays or radiation, and a high- or low-molecular weight compound having a group crosslinkable with an acid and having properties such that the solubility in an aqueous alkali developing solution decreases by the action of an acid; negative types of pattern forming materials, which contain a water-insoluble, silicone-containing polymer having an olefinically unsaturated group and having properties such that the solubility in an aqueous alkali developing solution decreases through a polymerization reaction, and a compound capable of generating polymerization reaction initiating ability with exposure to active light rays or radiation; and negative types of pattern forming materials, which contain a water-insoluble, aqueous alkali-soluble, silicone-containing polymer, a compound capable of generating polymerization reaction initiating ability with exposure to active light rays

or radiation, and a high- or low-molecular weight compound having an olefinically unsaturated group and having properties such that the solubility in an alkali developing solution decreases through a polymerization reaction.

[0072]

Among them, the pattern forming materials, which contain a water-insoluble, aqueous alkali-soluble, silicone-containing polymer, a compound capable of generating an acid with exposure to active light rays or radiation, and a high- or low-molecular weight compound having a group decomposable with an acid and having properties such that the solubility in an aqueous alkali developing solution increases by the action of an acid, are particularly preferable. Such pattern forming materials are described in detail in, for example, Japanese Patent Application No. 10(1998)-354878 with reference to the general formula, the explanation of the general formula, and examples. Pattern forming materials of the same types may be appropriately used for the present invention. Also, various additives capable of being added to the pattern forming materials are described in detail in Japanese Patent Application No. 10(1998)-354878. The additives of the same types may also be used for the present invention.

[0073]

Then, a process for producing an optical wavelength converting device in accordance with a third embodiment of the invention will be described hereinbelow with reference to FIG. 5. In the third embodiment, an optical stamp 40 is employed. The optical stamp 40 is constituted of a light-transmitting member capable of transmitting the exposure light and has a concavity-convexity pattern formed on one surface (the lower surface as viewed in FIG. 5), and the near field light is radiated from the concavity-convexity pattern. As shown, the optical stamp 40 is placed in contact with the resist layer 11. When the exposure light L is introduced into the optical stamp 40 and caused to undergo total reflection from the one surface of

the optical stamp 40, the resist layer 11 is exposed to the near field light Ln from the convex areas of the concavity-convexity pattern.

[0074]

After the exposure, the development of the resist, the formation of the electrode, and the domain inversion processing may be performed, for example, in the same manner as in the first embodiment. Since a metal is not used as in the aforesaid mask, the optical stamp 40 of this type has the advantage that it can be produced at low cost.

[0075]

Next a fourth embodiment of the invention will be described hereinbelow with reference to FIG. 6. In the fourth embodiment, scanning exposure utilizing a probe 50 is performed. The probe 50 is provided with an opening having a diameter shorter than the wavelength of the exposure light and radiates out the near field light. The probe 50 is driven by scanning drive means (not shown) to scan in a periodic pattern on the resist layer 11. In this manner, the resist layer 11 is exposed to the periodic pattern.

[0076]

Also in this case, after the resist layer 11 has been exposed to the near field light Ln, the development of the resist, the formation of the electrode, and the domain inversion processing may be performed, for example, in the same manner as in the first embodiment.

[0077]

The above-described exposure system employed in the third and fourth embodiments can also be applicable in cases where the double-layered resist is employed as in the second embodiment described above

[Brief Description of the Drawings]

[FIG. 1]

FIG. 1 shows schematic views for illustrating some steps of a process for producing an optical wavelength converting

device in accordance with a first embodiment of the present invention.

[FIG. 2]

FIG. 2 shows a schematic view for illustrating another step of the process for producing an optical wavelength converting device in accordance with the first embodiment.

[FIG. 3]

FIG. 3 is a side view of a solid laser which employs an optical wavelength converting device obtained according to the first embodiment.

[FIG. 4]

FIG. 4 shows schematic views for illustrating some steps of a process for producing an optical wavelength converting device in accordance with a second embodiment of the present invention.

[FIG. 5]

FIG. 5 shows schematic views for illustrating some steps of a process for producing an optical wavelength converting device in accordance with a third embodiment of the present invention.

[FIG. 6]

FIG. 6 shows schematic views for illustrating some steps of a process for producing an optical wavelength converting device in accordance with a fourth embodiment of the present invention.

[FIG. 7]

FIG. 7 is a graph showing results of evaluation of periodicity of various domain inversion structures, each of which is formed in a ferroelectric substance by the utilization of a periodic electrode having an electrode line width A, the evaluation being made with respect to various different values of a period Λ of domain inversion regions and various different values of a duty ratio D ($D=A/\Lambda$).

[Explanation of the Reference Numerals]

1: electrically conductive jig

2: grounding wire

3: corona wire

4: high voltage electric source

10: MgO-LN plate

10a: one surface of the MgO-LN plate

11: resist layer

11a: periodic pattern of resist layer

12: mask

12a: opening area of metal pattern

12b: metal area of metal pattern

13: Cr

13a: periodic electrode

20: optical wavelength converting device

21: periodic domain inversion region 21

22: Ar laser pumped titanium sapphire laser

23: laser beam (fundamental wave)

24: converging lens

25: second harmonic

30: Cr layer

30a: periodic electrode made of Cr

31: first resist layer

32: second resist layer

33: double-layered resist

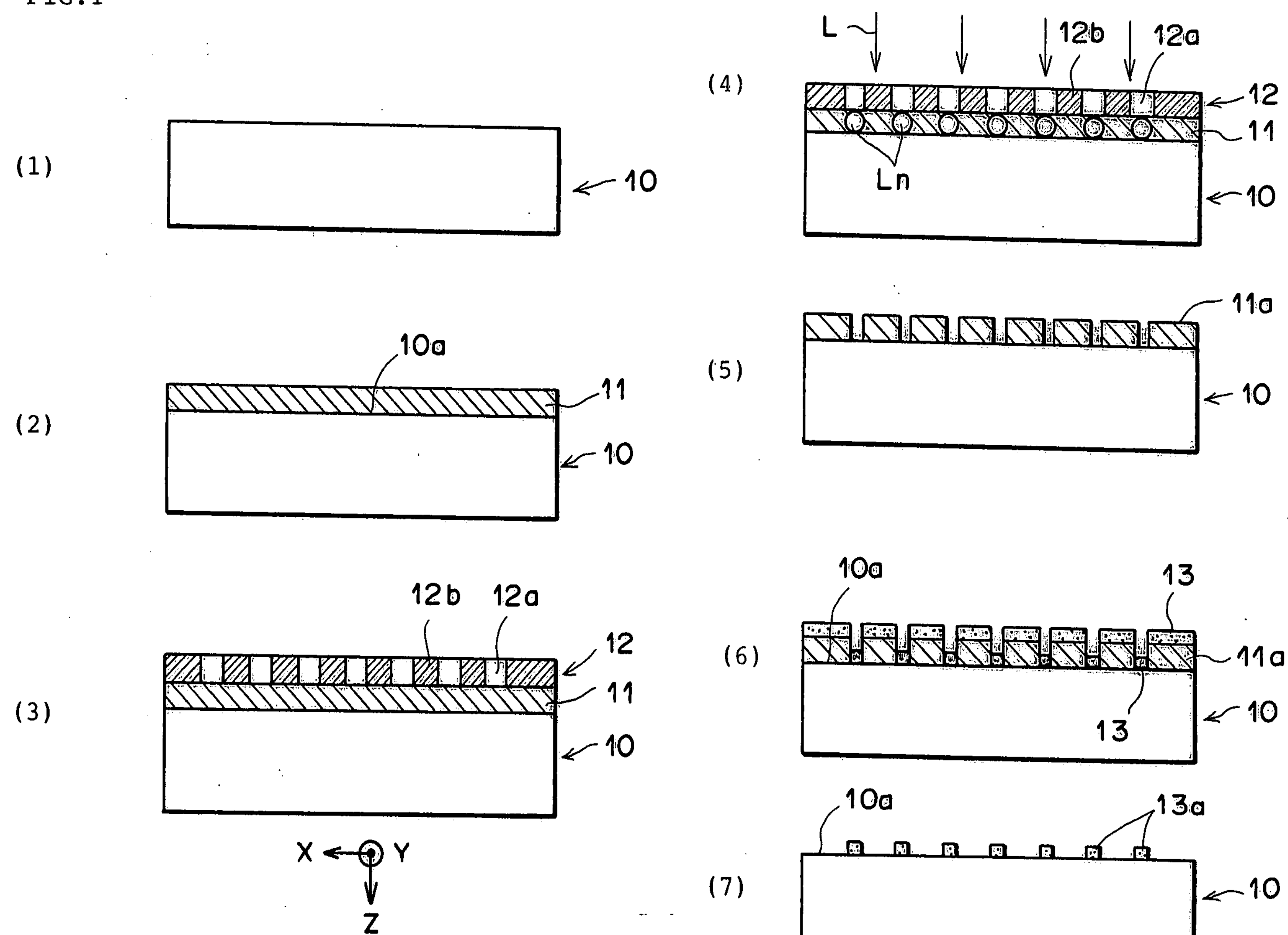
40: optical stamp

50: probe

L: exposure light

Ln: near field light

FIG.1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(3)
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12
11
Ln
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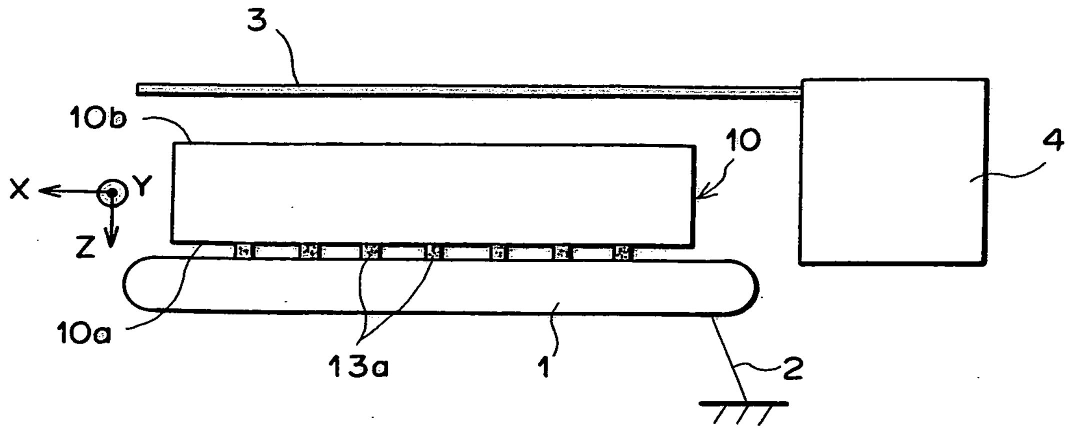
10

F I G . 2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13a
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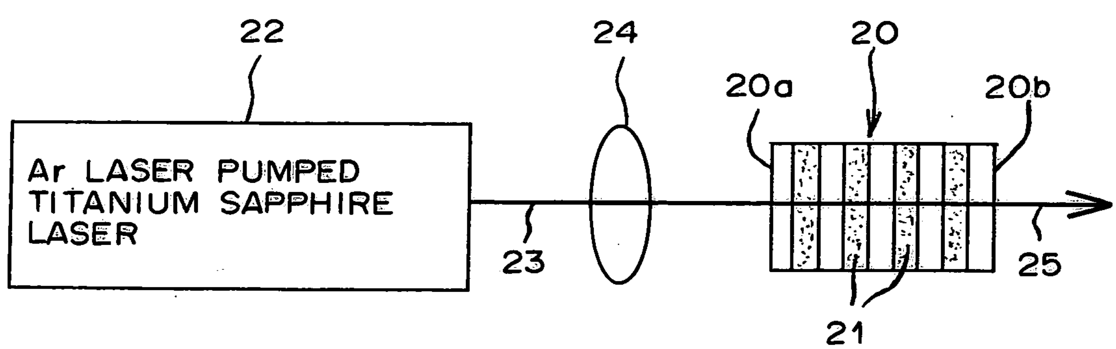
2

F I G . 3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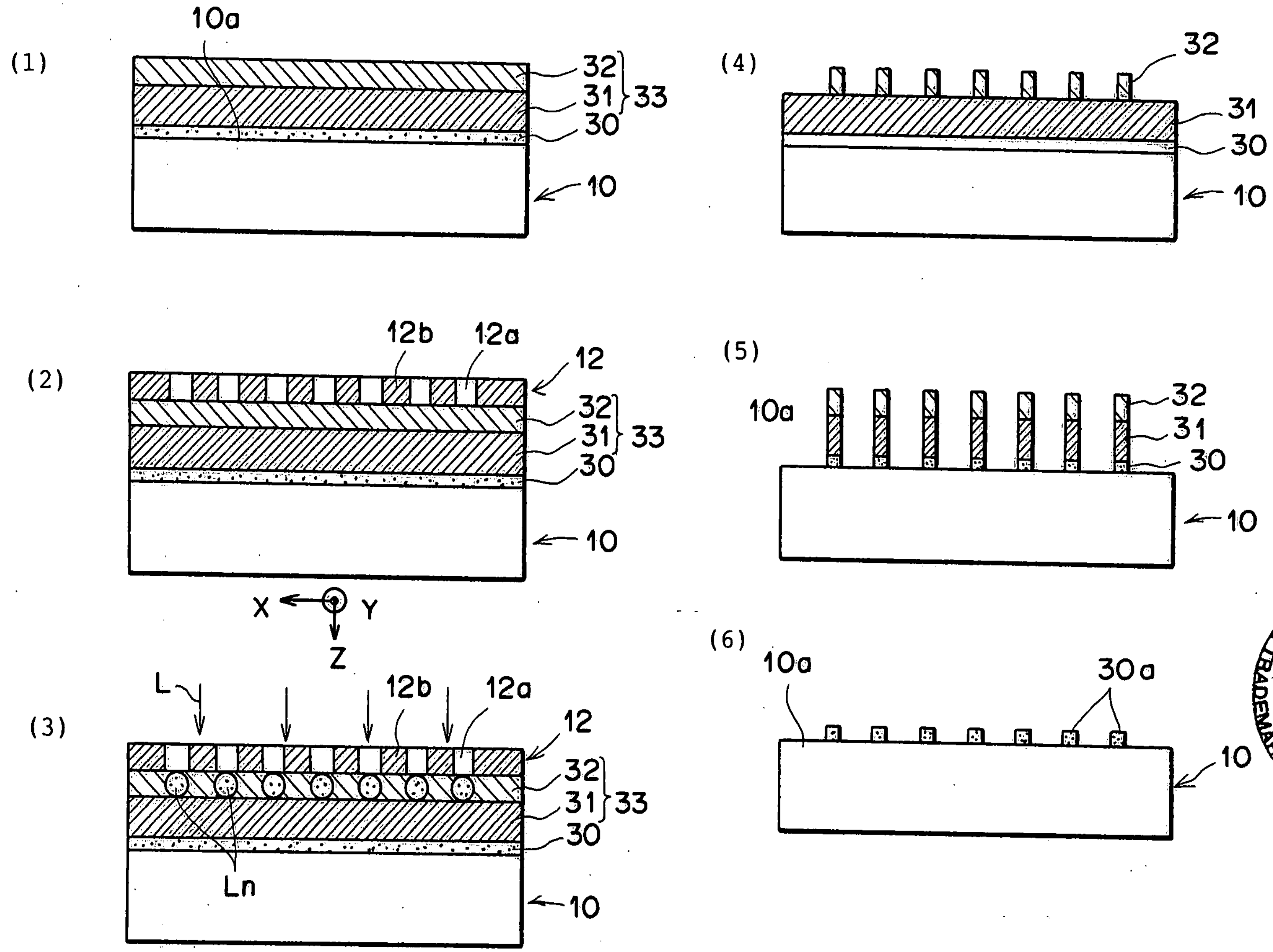
TITANIUM SAPPHIRE
LASER
23
25
21

FIG.4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Ln
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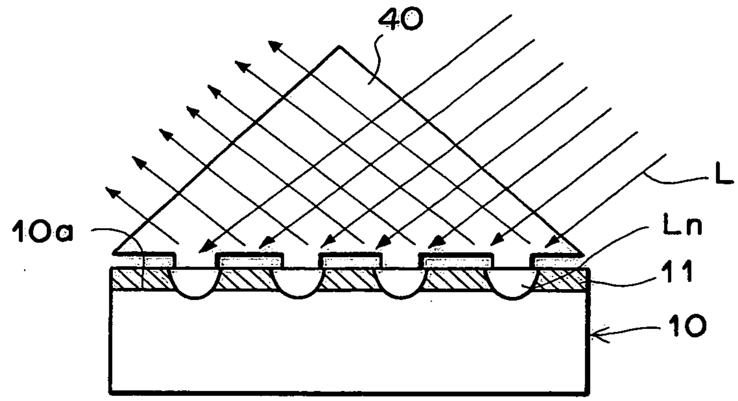
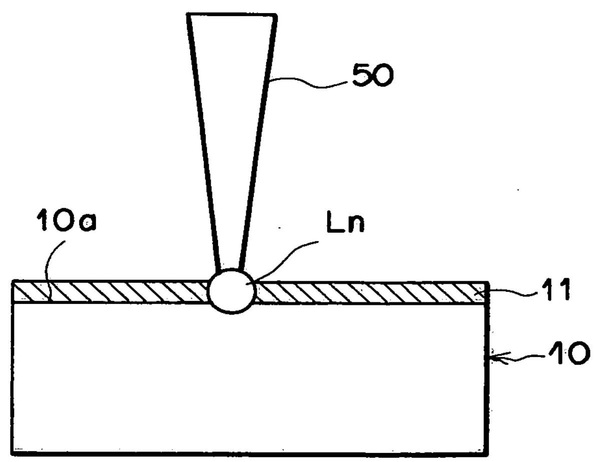
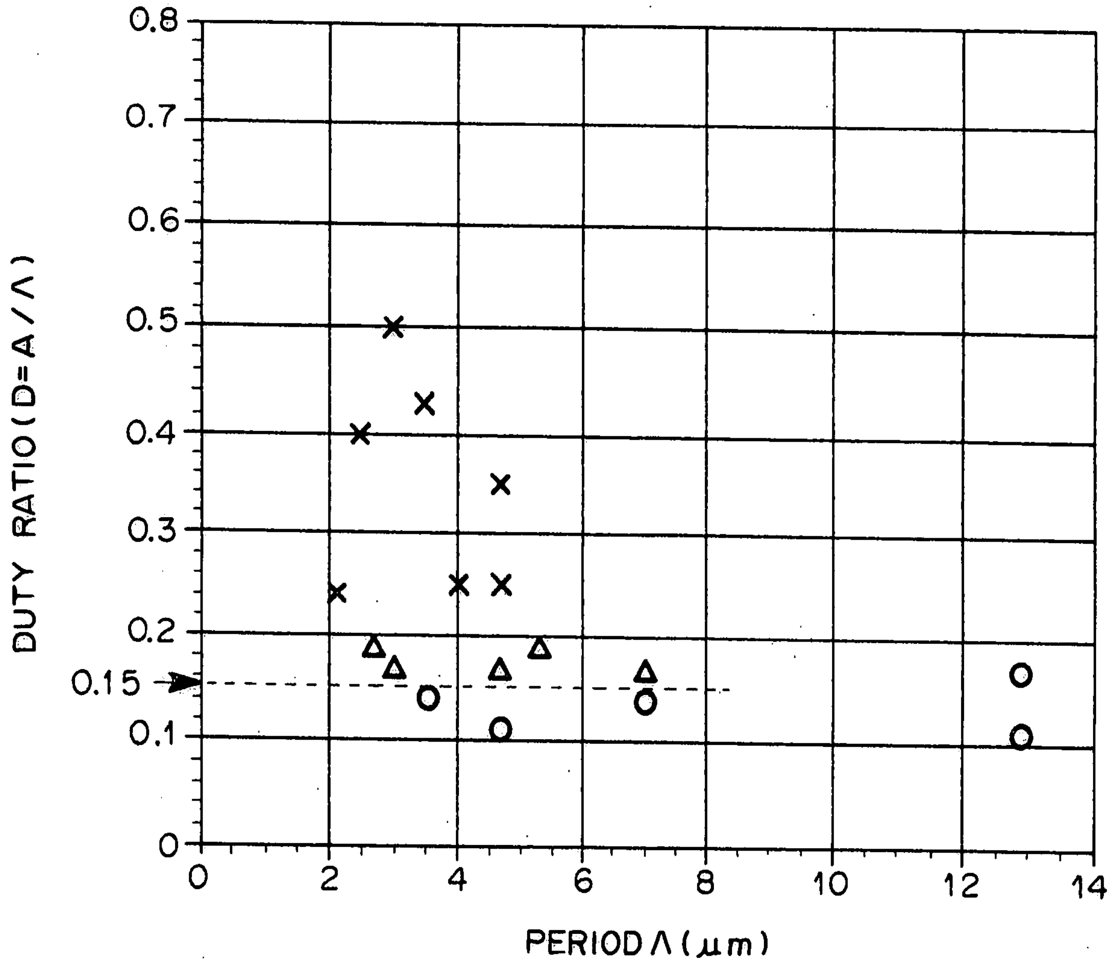
F I G . 5



F I G . 6



F I G . 7



DUTY RATIO (D=A/Λ)
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0.7
0.6
0.5
0.4
0.3
0.2
0.15
0.1
0
0
2
4
6
8
10
12
14
PERIOD Λ (μm)

[Name of Document] ABSTRACT

[Abstract]

[Objective] An optical wavelength converting device having a periodic domain inversion structure with a markedly short period is provided.

[Constitution] In a process for producing an optical wavelength converting device having a periodic domain inversion structure, in which a periodic electrode 13a is formed on one surface 10a of a single-polarized ferroelectric substance 10 having nonlinear optical effects, and then an electric field is applied across the ferroelectric substance 10 via the periodic electrode 13a in order to set regions of the ferroelectric substance, which stand facing the periodic electrode 13a of the ferroelectric substance 10, as local area limited domain inversion regions, a photosensitive resist layer 11 is formed on the one surface 10a of the ferroelectric substance 10. The resist layer 11 has properties such that, when light is irradiated to the resist layer, only exposed areas of the resist layer or only unexposed areas of the resist layer become soluble in a developing solvent. Then, in the process, the resist layer 11 is exposed to near field light Ln in a periodic pattern with means 12 for producing the near field light in the periodic pattern upon irradiation with exposure light. Subsequently, the resist layer 11 is developed to form a periodic pattern 11a in the resist layer, and the periodic electrode 13a is formed on the one surface of the ferroelectric substance 10 at positions corresponding to opening areas of the mask by utilizing the periodic pattern 11a as a mask.

[Selected Figure] FIG. 1